ACCESSING THE ACCELERATION OF THE UNIVERSE WITH SUNYAEV-ZELDOVICH AND X-RAY DATA FROM GALAXY CLUSTERS

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By using exclusively the Sunyaev-Zel'dovich effect and X-ray surface brightness data from 25 galaxy clusters in the redshift range $0.023 \leq z \leq 0.784$ we access cosmic acceleration employing a kinematic description. Such result is fully independent on the validity of any metric gravity theory, the possible matter-energy contents filling the Universe, as well as on the SNe Ia Hubble diagram.

Keywords: Sunyaev-Zeldovich Effect, Galaxy Clusters, Accelerated Universe.

1. Introduction

Currently, SNe type Ia provides a unique direct access to the late time accelerating stage of the Universe.[1] Naturally, this a rather uncomfortable situation from the observational and theoretical viewpoints. A promising distance estimator fully independent of SNe type Ia and other calibrators of the cosmic distance ladder is the angular diameter distance ($D_A(z)$) from a given set of distant objects.[2] It has also been recognized that the combination of SZE[3] and X-ray surface brightness measurements may provide useful angular diameters from galaxy clusters.[4–6]

De Filippis et al. (2005)[6] reanalyzed and derived, using an isothermal elliptical 2-Dimensional β-model to describe the clusters, $\mathcal{D}_A$ measurements for 25 clusters from two previous compilations,[7,8] where was used a spherical isothermal β model to describe the clusters geometry. More recently, it was shown[9,10] that De Filippis *et al.* sample is in good agreement with the distance duality (DD) relation between luminosity distance ($\mathcal{D}_L$) and angular diameter distance ($\mathcal{D}_A$), $\mathcal{D}_L(1+z)^{-2}/\mathcal{D}_A = 1$, in the context of a ΛCDM model (WMAP7).[11] This sample is also consistent (2σ c.l.) with no violation of the DD relation in a model-independent cosmological test involving D_A from galaxy clusters and D_L from the supernovae Ia data provided by the Constitution compilation.[12]

In this work, we investigate the potentialities of SZE/X-ray technique by employing a purely kinematic description of the universal expansion based on angular diameter distances of clusters for two different expansions of the deceleration pa-

rameter[13] : $q(z) = q_0 + q_1 z$ and $q(z) = q_0 + q_1 z/(1+z)$. As we shall see, by using the De Filippis *et al.*[6] sample we find that a kinematic analysis based uniquely on cluster data suggests that the Universe is accelerating today, such as, $q_0 < 0$ with 83% of probability.

2. Kinematic Approach and Constraints

Let us now assume that the Universe is spatially flat as motivated by inflation and WMAP measurements.[11] In this case, the angular diameter distance in the FRW metric is defined by (in our units $c = 1$),

$$D_A = (1+z)^{-1} H_0^{-1} \int_0^z \frac{du}{H(u)} = \frac{(1+z)^{-1}}{H_0} \int_0^z \exp\left[- \int_0^u [1+q(u)] d\ln(1+u) \right] du, \quad (1)$$

where $H(z) = \dot{a}/a$ is the Hubble parameter, and, $q(z)$, the deceleration parameter, is defined by

$$q(z) \equiv -\frac{a\ddot{a}}{\dot{a}^2} = \frac{dH^{-1}(z)}{dt} - 1. \quad (2)$$

Let us now consider the 25 measurements of angular diameter distances from galaxy clusters as obtained through SZE/X-ray method by De Filippis and coworkers.[6] In our analysis we use a maximum likelihood determined by a χ^2 statistics

$$\chi^2(z|\mathbf{p}) = \sum_i \frac{(\mathcal{D}_A(z_i;\mathbf{p}) - \mathcal{D}_{Ao,i})^2}{\sigma^2_{\mathcal{D}_{Ao,i}} + \sigma^2_{sys.}}, \quad (3)$$

where $\mathcal{D}_{Ao,i}$ is the observational angular diameter distance, $\sigma_{\mathcal{D}_{Ao,i}}$ is the uncertainty in the individual distance, σ_{sys} is the contribution of the systematic errors and the complete set of parameters is given by $\mathbf{p} \equiv (H_0, q_0, q_1)$. We have marginalized on the Hubble Distance (H_0^{-1}) with a gaussian prior on H_0 centered in our best fit value $H_0 = 77 \pm 4$ km/s/Mpc.

3. Results and Discussion

In Fig. 1(a) we show the contour in the plane $q_0 - q_1$ for linear parametrization. The confidence region (1σ) are $-3.2 \leq q_0 \leq 0.7$ and $29 \leq q_1 \leq -9$. In Fig. 1(b) we show the likelihood for q_0 (solid line-only statistical errors and dashed line-statistical + systematic errors). We have marginalized on the Hubble distance with a gaussian prior on H_0 centered in its best fit $H_0 = 77 \pm 4$ km/s/Mpc and on all values of q_1. We obtain that $q_0 < 0$ with 84% of probability, $q_0 = -1.29^{+1.31}_{-1.5}$ (1σ - only statistical errors) and 74% of probability, $q_0 = -0.8^{+1.6}_{-1.7}$ (1σ - statistical + systematic errors). In Figs. 1(c) and 1(d) we display the corresponding plots for the non linear parameterization. The confidence region (1σ) is now defined by:

$-3.5 \leq q_0 \leq 0.9$ and $-17 \leq q_1 \leq 27$. In Fig. 1(d) we show the likelihood distribution function for q_0. We obtain that $q_0 < 0$ with 82% of probability, $q_0 = -1.4^{+1.41}_{-1.6}$ (1σ - only statistical errors) and with 72% of probability, $q_0 = -1^{+1.7}_{-1.6}$ (1σ - statistical + systematic errors).

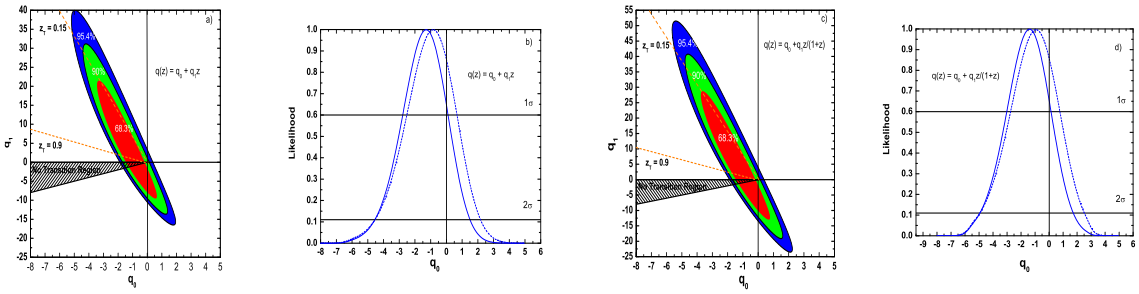

Fig. 1. **a)** Contours in the $q_o - q_1$ plane for 25 galaxy clusters data[6] considering $q(z) = q_0 + q_1 z$. **b)** Likelihood function for the q_0, marginalizing on all values of q_1. **c)** Contours in the $q_o - q_1$ plane considering $q(z) = q_0 + q_1 z/(1+z)$. **d)** Likelihood function for the q_0, marginalizing on all values of q_1 for non-linear parametrization.

We have shown that the combination of Sunyaev-Zeldovich/X-ray data from galaxy clusters is an interesting technique for accessing the present accelerating stage of the Universe. This result follows from a consistent kinematic approach based on the angular diameter distance of galaxy clusters obtained from SZE/X-ray measurements. By using two different parameterizations, it was found that $q_0 < 0$ with at least 83% probability (only statistical errors in galaxy clusters data) and 72% probability (statistical + systematic errors in galaxy clusters data).

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